DECLARATION

I, Mitsumasa ITAGAKI, hereby declare that I am fully conversant in English and Japanese and that the attached is an accurate translation of Japanese Patent Application No. 2002-266305 filed in the Japanese Patent Office on the 12th day of September, 2002.

Signed this 9th day of May, 2005

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[Title of the Invention] SOFT MAGNETIC FILM, THIN FILM

10 MAGNETIC HEAD USING THIS SOFT MAGNETIC FILM, METHOD FOR

MANUFACTURING THE SOFT MAGNETIC FILM AND METHOD FOR

MANUFACTURING THE THIN FILM MAGNETIC HEAD

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[Name of Document]   SPECIFICATION

[Title of the Invention]   SOFT MAGNETIC FILM, THIN FILM
MAGNETIC HEAD USING THIS SOFT MAGNETIC FILM, METHOD FOR
MANUFACTURING THE SOFT MAGNETIC FILM AND METHOD FOR
5   MANUFACTURING THE THIN FILM MAGNETIC HEAD

[Claims]

[Claim 1]   A soft magnetic film which comprises a plated
film composed of elements of Co and Fe and which is provided
to comprise a columnar crystal extending in the film
10   thickness direction.

[Claim 2]   The soft magnetic film according to Claim 1,
wherein a plurality of the columnar crystals are provided
side by side in the film surface direction with grain
boundaries extending in the film thickness direction
15   therebetween.

[Claim 3]   The soft magnetic film according to any one of
Claims 1 or 2, wherein the average crystal particle diameter
of the soft magnetic film is 200 angstroms or less.

[Claim 4]   The soft magnetic film according to any one of
20   Claims 1 to 3, wherein the center line average roughness Ra
of the film surface of the soft magnetic film is 2.5
angstroms or less.

[Claim 5]   A thin film magnetic head comprising a lower
core layer, an upper core layer and a magnetic pole portion
25   which is located between the lower core layer and the upper
core layer and which has the width dimension in the track-
width direction controlled to be smaller than that of the
lower core layer and the upper core layer,

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wherein the magnetic pole portion comprises a lower magnetic pole layer succeeding the lower core layer, an upper magnetic pole layer succeeding the upper core layer and a gap layer located between the lower magnetic pole layer and the

5   upper magnetic pole layer, or the magnetic pole portion comprises an upper magnetic pole layer succeeding the upper core layer and a gap layer located between the upper magnetic pole layer and the lower core layer, and

wherein the upper magnetic pole layer and/or the lower

10   magnetic pole layer comprises the soft magnetic film according to any one of Claims 1 to 4.

[Claim 6] A method for manufacturing a soft magnetic film, comprising the steps of adding malonic acid to a plating bath containing Fe ions and Co ions and forming a soft magnetic

15   film by plating, the soft magnetic film comprising elements of Co and Fe and comprising a columnar crystal extending in the film thickness direction.

[Claim 7] The method for manufacturing a soft magnetic film according to Claim 6, wherein the soft magnetic film is

20   formed by plating through an electroplating method with pulsed current.

[Claim 8] The method for manufacturing a soft magnetic film according to Claim 6 or 7, wherein the malonic acid is added to the plating bath within the range of 0.03 g/l or

25   more, but 0.25 g/l or less.

[Claim 9] The method for manufacturing a soft magnetic film according to Claim 6 or 7, wherein the malonic acid is added to the plating bath within the range of 0.03 g/l or

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more, but 0.05 g/l or less.

[Claim 10] A method for manufacturing a thin film magnetic head including a lower core layer, an upper core layer and a magnetic pole portion which is located between the lower core layer and the upper core layer and which has the width dimension in the track-width direction controlled to be smaller than that of the lower core layer and the upper core layer, comprising the steps of:

forming the magnetic pole portion from a lower magnetic pole layer succeeding the lower core layer, an upper magnetic pole layer succeeding the upper core layer and a gap layer located between the above-mentioned lower magnetic pole layer and the above-mentioned upper magnetic pole layer, or forming the magnetic pole portion from an upper magnetic pole layer succeeding the upper core layer and a gap layer located between the upper magnetic pole layer and the lower core layer; and

forming, at this time, the upper magnetic pole layer and/or the lower magnetic pole layer from the soft magnetic film by plating, the soft magnetic film being manufactured by the method according to any one of Claims 6 to 9.

[Detailed Description of the Invention]

[0001]

[Technical Field of the Invention]

The present invention relates to a soft magnetic film used as, for example, a magnetic pole portion of a recording inductive head. In particular, the present invention relates to a soft magnetic film which is composed of Co and Fe, which

contains no impurity, and which can improve both the saturation magnetic flux density and the corrosion resistance by microcrystallization, a thin film magnetic head using this soft magnetic film, a method for manufacturing the above-mentioned soft magnetic film and a method for manufacturing the above-mentioned thin film magnetic head.

[0002]

[Description of the Related Art]

In particular, in order to match a future increase in packing density, a magnetic material having a high saturation magnetic flux density Bs must be used for, e.g. a core layer of a thin film magnetic head, and thereby, magnetic fluxes must be concentrated on the vicinity of the gap of the above-mentioned core layer to improve the packing density.

[0003]

Conventionally, alloys containing Co and Fe have been frequently used for the above-mentioned magnetic material (refer to the following Patent literatures 1 to 5).

[0004]

[Patent literature 1]

Japanese Patent No. 3298930

[Patent literature 2]

Japanese Unexamined Patent Application Publication No. 7-57934

[Patent literature 3]

Japanese Unexamined Patent Application Publication No. 7-233494

[Patent literature 4]

Japanese Unexamined Patent Application Publication No. 2002-134318

[Patent literature 5]

Japanese Unexamined Patent Application Publication No. 2002-217029

[0005]

[Problems to be Solved by the Invention]

When a magnetic material containing Co and Fe is formed by plating, in general, sodium saccharin ($C_6H_4CONNaSO_2$) is added to a plating bath as a brightener (refer to, for example, Patent literature 2 and Patent literature 4).

[0006]

However, when sodium saccharin was added to a plating bath, there was a problem in that S (sulfur), as an impurity, contained in sodium saccharin was mixed with Fe, and thereby, corrosion was likely to occur. Furthermore, there was also a problem in that trivalent Fe ions and $Fe(OH)_3$ were increased in the plating bath, and the saturation magnetic flux density Bs was reduced when these Fe ions were taken into a plated film.

[0007]

In order to reduce corrosion of the above-mentioned magnetic material, it was considered that a noble metal unlikely to be ionized was added to a plating bath so as to form a $CoFe\alpha$ (α represents, for example, Rh) alloy. When the $CoFe\alpha$ alloy was provided, it was possible to actually reduce the corrosion compared with that in the case where no noble metal element α was added. On the other hand, it was

made clear that the saturation magnetic flux density Bs was further reduced, and an available saturation magnetic flux density was simply in the order of 2.2 T.

[0008]

A saturation magnetic flux density Bs in the order of 2.4 T can be ensured with respect to a bulk material composed of Co and Fe, and therefore, it is best that a saturation magnetic flux density Bs of 2.4 T or close to this can be achieved through the formation by plating. However, it was conventionally difficult to form the magnetic material containing Co and Fe by plating, while the magnetic material has a high saturation magnetic flux density Bs as well as the corrosion resistance.

[0009]

The present invention is to overcome the above-mentioned problems. In particular, it is an object of the present invention to provide a soft magnetic film which is composed of Co and Fe, which contains no impurity, e.g. S (sulfur) and which can improve both the saturation magnetic flux density and the corrosion resistance by microcrystallization, a thin film magnetic head using this soft magnetic film, a method for manufacturing the above-mentioned soft magnetic film and a method for manufacturing the above-mentioned thin film magnetic head.

[0010]

[Means for Solving the Problems]

A soft magnetic film of the present invention is a plated film composed of elements of Co and Fe and is provided

to include a columnar crystal extending in the film thickness direction.

[0011]

The soft magnetic film of the present invention is a plated film composed of Co and Fe, and impurities, e.g. S (sulfur), and noble metal elements, e.g. Rh, are not contained in this plated film in contrast to a conventional plated film. With respect to the soft magnetic film of the present invention, as described below, malonic acid is added to a plating bath. In a soft magnetic film thereby formed by plating, crystals were made fine, and surface roughness of the film surface was improved. In the soft magnetic film formed by plating while malonic acid was added to the plating bath, as in the present invention, columnar crystals extending in the film thickness direction were formed. On the other hand, in the soft magnetic film resulting from no addition of malonic acid, the above-mentioned columnar crystal was not formed. The above-mentioned columnar crystal may be formed by piling up of a plurality of fine crystals, or be a lump of a single crystal. However, it is believed that the columnar crystal is preferably formed by piling up of a plurality of fine crystals, and thereby, an increase in saturation magnetic flux density Bs and reduction in coercive force Hc can be accelerated in addition to an improvement in the corrosion resistance.

[0012]

In the present invention, an improvement in the corrosion resistance is not performed by addition of the

noble metal to the CoFe alloy in contrast to a conventional manner. A columnar crystal extending in the film thickness direction is formed, and thereby, an improvement in the surface roughness of the film surface and an improvement in the corrosion resistance can be achieved. Furthermore, the saturation magnetic flux density Bs can also be improved by making the crystal fine and eliminating the need for addition of the noble metal element. With respect to the saturation magnetic flux density, since the above-mentioned soft magnetic film is formed by plating while Fe ions are primarily in the state of Fe^{2+}, as described below, further improvement in the saturation magnetic flux density Bs can be achieved. Specifically, in the present invention, the saturation magnetic flux density of 2.35 T or more can be achieved.

[0013]

In the present invention, preferably, a plurality of the above-mentioned columnar crystals are provided side by side in the film surface direction with grain boundaries extending in the film thickness direction therebetween in order that the surface roughness of the film surface is reduced, an improvement in the corrosion resistance can thereby be achieved, and furthermore, the saturation magnetic flux density is improved.

[0014]

In the present invention, preferably, the average crystal particle diameter of the above-mentioned soft magnetic film is 200 angstroms or less. Preferably, the

center line average roughness Ra of the film surface of the above-mentioned soft magnetic film is 2.5 angstroms or less. In the soft magnetic film of the present invention, as described above, the average crystal particle diameter and

5   the center line average roughness Ra of the film surface can be reduced. As a result, an improvement in the corrosion resistance, an improvement in the saturation magnetic flux density Bs, and reduction in the coercive force Hc can be appropriately achieved.

10   [0015]

A thin film magnetic head of the present invention includes a lower core layer, an upper core layer and a magnetic pole portion which is located between the above-mentioned lower core layer and upper core layer and which has

15   the width dimension in the track-width direction controlled to be smaller than that of the above-mentioned lower core layer and upper core layer,

wherein the above-mentioned magnetic pole portion is composed of a lower magnetic pole layer succeeding the lower

20   core layer, an upper magnetic pole layer succeeding the upper core layer and a gap layer located between the above-mentioned lower magnetic pole layer and the above-mentioned upper magnetic pole layer, or the above-mentioned magnetic pole portion is composed of an upper magnetic pole layer

25   succeeding the upper core layer and a gap layer located between the above-mentioned upper magnetic pole layer and the lower core layer, and

wherein the above-mentioned upper magnetic pole layer

and/or the lower magnetic pole layer is formed from any one
of the above-mentioned soft magnetic films.

[0016]

In the above-mentioned thin film magnetic head, the
magnetic pole portion for controlling the track width is
provide between the lower core layer and the upper core layer,
and the soft magnetic film of the present invention can be
used for this magnetic pole portion. The above-mentioned
magnetic pole portion has a structure composed of, for
example, the upper magnetic pole layer, the lower magnetic
pole layer and the gap layer sandwiched therebetween, and
signals are written into a medium through the recording
magnetic field leaking from the upper and lower magnetic pole
layers. Consequently, it is better that the saturation
magnetic flux density Bs of the above-mentioned magnetic pole
layer is higher. By using the soft magnetic film of the
present invention for the above-mentioned magnetic pole layer,
a thin film magnetic head capable of appropriately matching
an increase in packing density can be formed. Furthermore,
since the surface roughness of the film surface of the above-
mentioned magnetic pole layer is small, the above-mentioned
gap layer can be easily formed into a predetermined shape on
the flattened lower magnetic pole layer, and as a result, a
thin film magnetic head having excellent recording
characteristics can be manufactured.

[0017]

A method for manufacturing the soft magnetic film of the
present invention includes the steps of adding malonic acid

to a plating bath containing Fe ions and Co ions and forming a soft magnetic film by plating, while the soft magnetic film is composed of elements of Co and Fe and includes a columnar crystal extending in the film thickness direction.

[0018]

Malonic acid ($HO-OCCH_2COOH$) is a complexing agent. When the above-mentioned malonic acid is added to the plating bath, Fe^{3+} in the plating bath forms a complex compound with the above-mentioned malonic acid, and this is unlikely to be taken into a plated film. On the other hand, Fe^{2+} is likely to be taken into a soft magnetic film formed by plating together with Co ions. Consequently, it is believed that the soft magnetic film is formed by plating while Fe^{2+} is primarily taken therein during formation. In the present invention, an improvement in the corrosion resistance of the above-mentioned soft magnetic film is achieved by addition of malonic acid to the plating bath, and therefore, impurities, such as S (sulfur), which conventionally cause corrosion are not mixed into the plating bath.

[0019]

As a result of the above-mentioned addition of malonic acid to the plating bath, degradation of the above-mentioned plating bath can be reduced than ever. Since the above-mentioned malonic acid is added, crystal in the soft magnetic film formed by plating can be made fine, deposition of Fe^{3+} in the above-mentioned soft magnetic film can be reduced. Consequently, the manufacturing method of the present invention can improve both of the corrosion resistance and

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the saturation magnetic flux density Bs of the above-mentioned soft magnetic film.

[0020]

In the present invention, preferably, the above-mentioned soft magnetic film is formed by plating through an electroplating method with pulsed current. In the electroplating method with pulsed current, for example, by repeating ON/OFF of a current-controlling element, times in which current is passed and blank times in which no current is passed are provided during formation of the plating. When the times in which no current is passed are provided, as described above, an effect of agitating the plating solution is enhanced, and the content of Fe contained in the soft magnetic film can be increased. Furthermore, a CoFe alloy film is formed little by little by plating, and thereby, uneven distribution of the current density during formation of the plating can be reduced compared with that in an electroplating method with direct current. According to the electroplating method with pulsed current, crystals in the state of fine columnar crystals can be deposited in the film surface direction with grain boundaries therebetween in the above-mentioned soft magnetic film, microcrystallization of the crystals constituting the above-mentioned columnar crystals can be accelerated, and the surface roughness can be appropriately controlled compared with that in an electroplating method with direct current.

[0021]

In the present invention, preferably, the above-

mentioned malonic acid is added to the plating bath within the range of 0.03 g/l or more, but 0.25 g/l or less. More preferably, the above-mentioned malonic acid is added to the plating bath within the range of 0.03 g/l or more, but 0.05 g/l or less.

[0022]

In this manner, microcrystallization in the soft magnetic film formed by plating can be accelerated, the surface roughness can be effectively reduced, the saturation magnetic flux density Bs can be improved, and in addition, the coercive force Hc can be reduced.

[0023]

A method for manufacturing a thin film magnetic head of the present invention, the thin film magnetic head including a lower core layer, an upper core layer and a magnetic pole portion which is located between the lower core layer and the upper core layer and which has the width dimension in the track-width direction controlled to be smaller than that of the lower core layer and the upper core layer, includes the steps of

forming the above-mentioned magnetic pole portion from a lower magnetic pole layer succeeding the lower core layer, an upper magnetic pole layer succeeding the upper core layer and a gap layer located between the above-mentioned lower magnetic pole layer and the above-mentioned upper magnetic pole layer, or forming the above-mentioned magnetic pole portion from an upper magnetic pole layer succeeding the upper core layer and a gap layer located between the above-

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mentioned upper magnetic pole layer and lower core layer, and

forming, at this time, the above-mentioned upper

magnetic pole layer and/or the above-mentioned lower magnetic

pole layer from the soft magnetic film by plating, while the

5   soft magnetic film is manufactured by any one of the above-

mentioned method.

[0024]

Since the above-mentioned upper magnetic pole layer

and/or lower magnetic pole layer is formed by plating using

10   the above-mentioned method for manufacturing a soft magnetic

film, a magnetic pole layer having excellent corrosion

resistance and a high saturation magnetic flux density Bs can

be formed with a high yield.

[0025]

15   [Description of the Embodiments]

Fig. 1 is a partial front view of a thin film magnetic

head according to a first embodiment of the present invention.

Fig. 2 is a vertical sectional view of the thin film magnetic

head shown in Fig. 1, cut along the line 2-2 and viewed from

20   the direction indicated by arrows.

[0026]

The thin film magnetic head in the present invention is

formed on a trailing-side end surface 11a of a ceramic slider

11 constituting a flying head, and is an MR/inductive

25   composite thin film magnetic head (hereafter simply referred

to as thin film magnetic head) in which an MR head h1 and a

writing inductive head h2 are laminated.

[0027]

The MR head h1 detects a leakage magnetic field from a recording medium, e.g. a hard disk, through the use of a magnetoresistance effect, and reads a recorded signal.

[0028]

As shown in Fig. 2, a lower shield layer 13 made of a magnetic material composed of NiFe or the like is provided on a trailing-side end surface 11a of the above-mentioned slider 11 with an Al_2O_3 film 12 therebetween, and a lower gap layer 14 made of an insulating material is further provided thereon.

[0029]

A magnetoresistive element 10, e.g. an anisotropic magnetoresistive (AMR) element, a giant magnetoresistive (GMR) element or a tunneling magnetoresistive (TMR) element, is provided on the above-mentioned lower gap layer 14 from a surface facing a recording medium toward the height direction (the Y direction shown in the drawing). An upper gap layer 15 made of an insulating material is further provided on the above-mentioned magnetoresistive element 10 and the lower gap layer 14. An upper shield layer 16 made of a magnetic material, e.g. NiFe, is further provided on the above-mentioned upper gap layer 15. The MR head h1 is composed of laminated films from the above-mentioned lower shield layer 13 to the upper shield layer 16.

[0030]

In the embodiment shown in Figs. 1 and 2, the above-mentioned upper shield layer 16 doubles as the lower core layer of the inductive head h2, a Gd-determining layer 17 is provided on the above-mentioned lower core layer 16, and a

gap depth (Gd) is controlled by the length dimension from the surface facing the recording medium to the end portion of the above-mentioned Gd-determining layer 17. The above-mentioned Gd-determining layer 17 is formed from, for example, an organic insulating material.

[0031]

As shown in Fig. 1, the top surface 16a of the above-mentioned lower core layer 16 is formed from inclined surfaces which are inclined downward in a direction farther from the base end of a magnetic pole portion 18 toward the track-width direction (the X direction shown in the drawing), and thereby, occurrence of side fringing can be reduced.

[0032]

As shown in Fig. 2, the magnetic pole portion 18 is provided from the surface facing the recording medium to the midpoint on the above-mentioned Gd-determining layer 17.

[0033]

In the above-mentioned magnetic pole portion 18, a lower magnetic pole layer 19, a non-magnetic gap layer 20 and an upper magnetic pole layer 21 are laminated from the bottom.

[0034]

The above-mentioned lower magnetic pole layer 19 is provided directly on the lower core layer 16 by plating. Preferably, the gap layer 20 provided on the above-mentioned lower magnetic pole layer 19 is made of a non-magnetic, metallic material which can be provided by plating. Specifically, the material is preferably at least one selected from the group consisting of NiP, NiPd, NiW, NiMo,

Au, Pt, Rh, Pd, Ru and Cr.

[0035]

As a specific embodiment in the present invention, NiP is used for the above-mentioned gap layer 20. This is because the above-mentioned gap layer 20 can be appropriately brought into a non-magnetic state when the above-mentioned gap layer 20 is formed from NiP.

[0036]

Furthermore, the upper magnetic pole layer 21 provided on the above-mentioned gap layer 20 is magnetically connected to an upper core layer 22 provided thereon.

[0037]

When the gap layer 20 is formed from a non-magnetic, metallic material which can be provided by plating, as described above, the lower magnetic pole layer 19, the gap layer 20 and the upper magnetic pole layer 21 can be successively formed by plating.

[0038]

The above-mentioned magnetic pole portion 18 may be composed of two layers of the gap layer 20 and the upper magnetic pole layer 21.

[0039]

As shown in Fig. 1, the above-mentioned magnetic pole portion 18 is provided to have the width dimension in the track-width direction (the X direction shown in the drawing) of a track width Tw.

[0040]

As shown in Fig. 1 and Fig. 2, an insulating layer 23 is

provided on both sides in the track-width direction (the X direction shown in the drawing) and the rear side in the height direction (the Y direction shown in the drawing) of the above-mentioned magnetic pole portion 18. The top surface of the above-mentioned insulating layer 23 is adjusted to be flush with the top surface of the above-mentioned magnetic pole portion 18.

[0041]

As shown in Fig. 2, a helical coil layer 24 is provided by patterning on the above-mentioned insulating layer 23. The above-mentioned coil layer 24 is covered with an insulating layer 25 made of an organic insulating material.

[0042]

As shown in Fig. 2, the upper core layer 22 is provided over the magnetic pole portion 18 and the insulating layer 25 by patterning through, for example, a frame plating method. As shown in Fig. 1, the front end 22a of the above-mentioned upper core layer 22 is provided to have a width dimension of T1 in the track-width direction on the surface facing the recording medium, and the above-mentioned width dimension T1 is adjusted to be larger than the track width Tw.

[0043]

As shown in Fig. 2, the base end 22b of the above-mentioned upper core layer 22 is directly connected onto a junction layer (back gap layer) 26 made of a magnetic material, provided on the lower core layer 16.

[0044]

In the present invention, the above-mentioned upper

magnetic pole layer 21 and/or lower magnetic pole layer 19 (hereafter referred to as magnetic pole layers 19 and 21) is formed from a plated film composed of elements of Co and Fe. Impurities, e.g. S (sulfur), and noble metal elements, e.g. Rh, are not contained in this plated film in contrast to conventional plated films.

[0045]

The above-mentioned magnetic pole layers 19 and 21 are formed by plating using a plating bath containing malonic acid, and thereby, the surface roughness of the film surface of the above-mentioned magnetic pole layers 19 and 21 is reduced because crystals are made fine.

[0046]

In the above-mentioned magnetic pole layers 19 and 21 formed by plating while malonic acid is added to the plating bath, columnar crystals extending in the film thickness direction (the Z direction shown in the drawing) are formed. On the other hand, in the magnetic pole layers 19 and 21 formed by plating without addition of malonic acid, the above-mentioned columnar crystal is not formed.

[0047]

The columnar crystals formed in the above-mentioned magnetic pole layers 19 and 21 may be provided by piling up of a plurality of fine crystals, or be lumps of single crystals. However, the columnar crystals are preferably formed by piling up of a plurality of fine crystals, and thereby, an increase in saturation magnetic flux density Bs and reduction in coercive force Hc can be accelerated in

addition to an improvement in the corrosion resistance.

[0048]

The reason for the formation of the columnar crystals in the above-mentioned magnetic pole layers 19 and 21 formed by plating is believed that microcrystallization is accelerated by the addition of malonic acid to the plating bath, and the resulting fine crystals epitaxially grow during plating.

[0049]

Preferably, the crystal structure of the above-mentioned magnetic pole layers 19 and 21 composed of elements of Co and Fe is a body-centered cubic structure (bcc). Preferably, the (111) plane of the above-mentioned columnar crystal exhibits preferred orientation in the direction parallel to the film surface (plane parallel to the X-Y plane shown in the drawing). When the above-mentioned pole layers 19 and 21 have a body-centered cubic structure, and the (111) plane exhibits preferred orientation in the direction parallel to the film surface, as described above, the crystallinity is excellent, and the above-mentioned pole layers 19 and 21 effectively, epitaxially grow during plating. Consequently, further reduction in surface roughness of the film surface can be accelerated, and the above-mentioned pole layers 19 and 21 having excellent corrosion resistance can be formed.

[0050]

In the above-mentioned magnetic pole layers 19 and 21, fine crystals constitute the columnar crystals, and in addition, the above-mentioned magnetic pole layers 19 and 21 are formed by plating while Fe ions are primarily in the

state of Fe^{2+}. Conventionally, there was a problem in that Fe ions contained in the plating bath were likely to become trivalent Fe ions or $Fe(OH)_3$ because of oxidation of divalent Fe ions, and when these ions were taken into a soft magnetic film together with Co ions, the saturation magnetic flux density Bs of the above-mentioned soft magnetic film was reduced. However, in the magnetic pole layers 19 and 21 shown in Fig. 1 and Fig. 2, as described above, Fe ions are formed by plating primarily in the state of Fe^{2+}, and therefore, the saturation magnetic flux densities Bs of the above-mentioned magnetic pole layers 19 and 21 can be further improved. Since a complexing agent, malonic acid, was added to the plating bath, Fe^{2+} was easily taken into the magnetic pole layers 19 and 21, as described above.

[0051]

In order to improve the above-mentioned saturation magnetic flux density Bs, it is also important to appropriately adjust the amount of Fe in the magnetic pole layers 19 and 21, and it is believed that when the above-mentioned amount of Fe is adjusted to be 60% by mass or more, but 80% by mass or less, the saturation magnetic flux density Bs of the above-mentioned magnetic pole layers 19 and 21 can be increased to 2.35 T or more. The saturation magnetic flux density Bs of the bulk material formed from a CoFe alloy is in the order of 2.4 T. Therefore, the saturation magnetic flux densities Bs of the magnetic pole layers 19 and 21 shown in Fig. 1 and Fig. 2 can be brought very close to the saturation magnetic flux density Bs of the bulk material.

Preferably, the above-mentioned amount of Fe is adjusted to be 60% by mass or more, but 70% by mass or less, because the saturation magnetic flux density of 2.35 T or more can be reliably achieved.

5   [0052]

In the above-mentioned magnetic pole layers 19 and 21, preferably, a plurality of the above-mentioned columnar crystals are formed, and the columnar crystals are in a state of being provided side by side with grain boundaries
10 therebetween in the film surface direction. More preferably, these columnar crystals are provided all over the film, with grain boundaries therebetween in the film surface direction. That the above-mentioned magnetic pole layers 19 and 21 are in such a state refers to that the crystallinity is very good,
15 and microcrystallization in the above-mentioned magnetic pole layers 19 and 21 is in a state of being accelerated. Consequently, the surface roughness of the film surface of the above-mentioned magnetic pole layers 19 and 21 can be further reduced, and further improvement in the saturation
20 magnetic flux density Bs and further reduction in the coercive force Hc can be achieved.

    [0053]

The above-mentioned magnetic pole layers 19 and 21 are microcrystallized to have average crystal particle diameters
25 smaller than ever, and the average crystal particle diameters of the above-mentioned magnetic pole layers 19 and 21 can be reduced to 200 angstroms or less. Furthermore, crystals in the above-mentioned magnetic pole layers 19 and 21 are

microcrystallized to have excellent crystallinity, and therefore, the columnar crystals are formed, so that the surface roughness can be reduced, and the center line average roughness Ra of the above-mentioned magnetic pole layers 19

5   and 21 can be reduced to 2.5 angstroms or less.

[0054]

With respect to the magnetic characteristics other than the saturation magnetic flux density Bs, the coercive force Hc can be reduced to 1,185 (A/m) (= 15 Oe) or less, and the

10   specific resistance of 20 ($\mu\Omega \cdot cm$) or more can be achieved.

[0055]

On the other hand, the film stress is sometimes increased to the order of 1,200 MPa. However, the lower magnetic pole layer 19 and the upper magnetic pole layer 21

15   constituting the above-mentioned magnetic pole portion 18 have very reduced film thicknesses (in the order of 0.3 μm with respect to the lower magnetic pole layer 19 and in the range of 0.3 to 0.5 μm with respect to the upper magnetic pole layer 21) and very small width dimensions in the track-

20   width direction. Since the above-mentioned magnetic pole layers 19 and 21 are formed in a very small region, as described above, it is believed that even when the film stress is somewhat high, the recording characteristics are not adversely affected, and the magnetic pole layers 19 and

25   21 are required to have rather higher saturation magnetic flux density Bs. Since, as described above, the magnetic pole layers 19 and 21 shown in Fig. 1 and Fig. 2 can achieve high saturation magnetic flux densities of 2.35 T or more,

formation of magnetic pole layers 19 and 21 suitable for further effectively achieving a future increase in packing density can be realized. Furthermore, since the surface roughness of the film surface of the above-mentioned lower

5   magnetic pole layer 19 is small, the gap layer 20 to be provided on the above-mentioned lower magnetic pole layer 19 can be formed on a flattened surface. In this manner, the above-mentioned gap layer 20 can be formed into the shape of a predetermined rectangle in the direction parallel to the

10 track-width direction (the X direction shown in the drawing), the conventional curved shape of the above-mentioned gap layer 20 due to roughness of the film surface of the above-mentioned lower magnetic pole layer 19 is improved, and a thin film magnetic head having excellent recording

15 characteristics can be formed.

[0056]

As described above, the magnetic pole layers 19 and 21 shown in Fig. 1 and Fig. 2 are plated films composed of elements of Co and Fe, and are provided to include columnar

20 crystals extending in the film thickness direction. Consequently, both of the corrosion resistance and the saturation magnetic flux density Bs of the above-mentioned magnetic pole layers 19 and 21 can be improved.

[0057]

25 Fig. 3 is a vertical sectional view of a thin film magnetic head according to a second embodiment of the present invention.

In this embodiment, an MR head h1 is the same as that

shown in Fig. 1. As shown in Fig. 3, a magnetic gap layer

(non-magnetic material layer) 41 made of alumina or the like

is provided on a lower core layer 16. A coil layer 44 is

provided on the above-mentioned magnetic gap layer 41 with an

5   insulating layer 43 made of polyimide or a resist material

therebetween by patterning to have a two-dimensionally

helical shape. The above-mentioned coil layer 44 is formed

from a non-magnetic conductive material, e.g. Cu (copper),

having a small electrical resistance.

10   [0058]

Furthermore, the above-mentioned coil layer 44 is

surrounded by an insulating layer 45 formed from polyimide or

a resist material, and an upper core layer 46 made of a soft

magnetic material is provided on the above-mentioned

15   insulating layer 45.

[0059]

As shown in Fig. 3, on the surface facing a recording

medium, the front end 46a of the above-mentioned upper core

layer 46 faces onto the lower core layer 16 with the above-

20   mentioned magnetic gap layer 41 therebetween, and the

magnetic gap having a magnetic gap length of Gl1 is provided.

The base end 46b of the upper core layer 46 is magnetically

connected to the lower core layer 16, as shown in Fig. 3.

[0060]

25   In a manner similar to that in the magnetic pole layers

19 and 21 described with reference to Fig. 1 and Fig. 2, the

lower core layer 16 and/or the upper core layer 46 (hereafter

referred to as core layers 16 and 46) shown in Fig. 3 is a

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plated film composed of elements of Co and Fe, and is provided to include columnar crystals extending in the film thickness direction. According to the core layers 16 and 46, both of the corrosion resistance and the saturation magnetic flux density Bs can be further effectively improved.

[0061]

A method for forming the magnetic pole layers 19 and 21 shown in Fig. 1 and Fig. 2 by plating will be described below.

[0062]

A plating bath for forming the above-mentioned magnetic pole layers 19 and 21 by plating contains Co ions and Fe ions, and furthermore, malonic acid ($HO-OCCH_2COOH$) is also added thereto.

[0063]

The above-mentioned malonic acid is a complexing agent. When the above-mentioned malonic acid is added to the plating bath, Fe^{3+} in the plating bath forms a complex compound with the above-mentioned malonic acid, and this is unlikely to be taken into a plated film.

[0064]

On the other hand, Fe^{2+} in the plating bath is likely to be taken into formation regions of the magnetic pole layers 19 and 21 formed by plating together with Co ions. Consequently, it is believed that the magnetic pole layers 19 and 21 are provided by plating while Fe^{2+} is primarily taken therein during formation.

[0065]

Boric acid (H_3BO_3) and NaCl to become pH buffers of the

electrode surface are added to the above-mentioned plating bath. However, sodium saccharin ($C_6H_4CONNaSO_2$) or the like containing impurities, such as S (sulfur), which conventionally cause corrosion, is not added. Likewise, a compound containing noble metal element, e.g. Rh, which is conventionally added to improve the corrosion resistance, is not added.

[0066]

As a result of the above-mentioned addition of malonic acid to the plating bath, degradation of the above-mentioned plating bath can be reduced than ever. When the above-mentioned malonic acid is added, with respect to the magnetic pole layers 19 and 21, fine crystals are epitaxially piled up in the film thickness direction during plating. Consequently, columnar crystals extending in the film thickness direction are formed in the above-mentioned magnetic pole layers 19 and 21, deposition of Fe^{3+} in the magnetic pole layers 19 and 21 can be reduced, and furthermore, impurities, such as S (sulfur), and a noble metal element, other than Co and Fe, are not contained in the above-mentioned magnetic pole layers 19 and 21.

[0067]

Preferably, the above-mentioned magnetic pole layers 19 and 21 are formed by plating through an electroplating method with pulsed current.

[0068]

In the electroplating method with pulsed current, for example, by repeating ON/OFF of a current-controlling element,

times in which current is passed and blank times in which no current is passed are provided during formation of the plating. When the times in which no current is passed are provided, as described above, the magnetic pole layers 19 and 21 are formed little by little by plating, and even the concentration of Fe ions contained in the plating bath is increased, uneven distribution of the current density can be reduced during the formation of the plating compared with that in the conventional electroplating with direct current.

[0069]

With respect to the pulsed current, preferably, ON/OFF is repeated in a cycle of, for example, a few seconds, and the duty ratio is adjusted to be in the range of 0.1 to 0.5. The condition of the pulsed current exerts an influence on the average crystal particle diameter of the CoFe alloy and the center line average roughness Ra of the film surface.

[0070]

As described above, since the electroplating method with pulsed current can reduce uneven distribution of the current density during the formation of the plating, crystals in the above-mentioned magnetic pole layers 19 and 21 can be made finer, and a plurality of columnar crystals can be easily formed in the film surface direction with crystal particle diameters extending in the film thickness direction therebetween compared with that in the conventional electroplating method with direct current. Preferably, the above-mentioned columnar crystals can be formed all over the film, and in addition, the content of Fe contained in the

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above-mentioned magnetic pole layers 19 and 21 can be increased than ever.

[0071]

When the above-mentioned electroplating method with pulsed current is adopted, the flexibility in adjustment of the compositional ratio is increased compared with that in the conventional electroplating method with direct current. Consequently, the amount of Fe in the magnetic pole layers 19 and 21 composed of elements of Co and Fe can be easily adjusted within the range of 60% by mass to 80% by mass, and preferably, within the range of 60% by mass to 70% by mass.

[0072]

As described above, crystals in the magnetic pole layers 19 and 21 formed by plating using the plating bath containing malonic acid are made fine, and columnar crystals extending in the film thickness direction are formed in the above-mentioned magnetic pole layers 19 and 21. In particular, since the electroplating method with pulsed current is adopted, further microcrystallization and an increase in the amount of Fe contained in the above-mentioned magnetic pole layers 19 and 21 are accelerated. As a result, the magnetic pole layers 19 and 21 having improved corrosion resistance as well as a high saturation magnetic flux density Bs can be formed with ease.

[0073]

In the formation of the above-mentioned magnetic pole layers 19 and 21 by plating, even when the electroplating method with direct current is adopted, columnar crystals

extending in the film thickness direction can be formed in the above-mentioned magnetic pole layers 19 and 21. However, when the electroplating method with pulsed current is adopted, crystals are likely to be made fine because of reduction in the film stress and reduction in the plating rate, and thereby, further improvement in the corrosion resistance and an increase in the saturation magnetic flux density Bs can be achieved.

[0074]

Preferably, the above-mentioned malonic acid is added to the above-mentioned plating bath within the range of 0.03 g/l or more, but 0.25 g/l or less, and more preferably, is added to the plating bath within the range of 0.03 g/l or more, but 0.05 g/l or less.

[0075]

According to the experimental results described below, by adjusting the amount of addition of the above-mentioned malonic acid to be within the above-mentioned range, microcrystallization in the above-mentioned magnetic pole layers 19 and 21 can be accelerated, fine columnar crystals can be deposited over a wider range in the film, the surface roughness of the film surface can be effectively reduced, the saturation magnetic flux density Bs can be improved, and in addition, the coercive force Hc can be reduced.

[0076]

The upper core layer 46 and/or lower core layer 16 shown in Fig. 3 can also be formed by plating using the above-mentioned plating bath containing malonic acid.

[0077]

In the present invention, the thin film magnetic heads shown in Fig. 1 to Fig. 3 were proposed as uses of the soft magnetic film made of elements of Co and Fe, although not limited to these uses. For example, the above-mentioned soft magnetic film made of elements of Co and Fe can also be used for flat-type magnetic elements, such as thin film inductors, and the like.

[0078]

[Examples]

In the present invention, a CoFe alloy was formed by plating using a plating bath described below through an electroplating method. At this time, the relationship between the compositional ratio of the above-mentioned CoFe alloy and soft magnetic characteristics as well as film characteristics were examined.

[0079]

Each of plating bath conditions and film forming conditions with respect to Example (CoFe alloys formed by plating using a plating bath containing malonic acid, but without saccharin), Comparative example 1 (alloys containing Co and Fe formed by plating using a plating bath containing saccharin), Comparative example 2 (alloys containing Co and Fe formed by plating using a plating bath without saccharin) and Comparative example 3 (a CoFeRh alloy) is shown in Table 1.

[0080]

[Table 1]

	Composition [mass%]				Fe ion [g/l]	Co ion [g/l]	Fe/Co	Malonic acid [g/l]	Saccharin [g/l]	Current density [mA/cm²]	Duty ratio	pH	Temp	4πNs [T]	Hch [Oe]	Cryst. particle dia. [Å]	Surface roughness [nm]	Film stress [MPa]	Sp. resistance [μΩcm]
	Fe	Co	Ni	Rh															
	59.9	40.1	–	–	4.02	4.12	0.95	–	–					2.2	23.8	358	21.8	83	23.4
	63.8	36.3	–	–	4.02	3.43	1.14	–	–					2.2	18.5	308	14.1	208	27.0
	66.8	33.2	–	–	4.02	2.97	1.31	–	–					2.2	17.0		9.4	222	27.3
	68.6	31.4	–	–	1.23	0.57	2.08	–	–					2.3	17.2	212	8.1	327	28.1
	70.8	29.2	–	–	1.23	0.69	1.74	–	–					2.3	15.8	301	7.3	318	28.6
	71.0	29.1	–	–	1.23	0.57	2.08	–	–					2.3	15.2	276	6.6	329	27.4
Comp. ex. 1	71.4	28.8	–	–	1.23	0.57	2.08	–	–					2.3	14.3	264	6.3	313	26.9
	71.4	28.7	–	–	1.23	0.57	2.08	–	–					2.3	14.3	277	8.1	365	26.5
	71.7	28.3	–	–	1.23	0.57	2.08	–	–					2.3	15.4	266	6.6	328	27.9
	71.7	28.3	–	–	1.23	0.57	2.08	–	–					2.2	18.6	267	4.5	382	27.3
	71.8	28.2	–	–	1.23	0.57	2.08	–	–					2.2	18.3	233	6.2	341	26.8
	72.3	27.7	–	–	1.23	0.57	2.08	–	–					2.2	14.7	277	6.0	386	27.2
	72.8	27.2	–	–	1.23	0.57	2.08	–	–					2.3	18.8	280	3.9	382	27.0
	72.9	27.1	–	–	1.23	0.57	2.08	–	–					2.3	15.6	286	4.6	355	27.6
	73.0	27.1	–	–	1.23	0.57	2.08	–	–					2.3	15.8	301	4.2	356	27.2
	73.7	26.3	–	–	1.23	0.57	2.08	–	–					2.3	18.8	308	5.3	385	26.3
	79.5	20.5	–	–	4.02	1.60	2.44	–	–					2.2	16.2	326	10.6	291	31.7
	83.0	17.0	–	–	4.02	1.26	3.11	–	–					2.2	14.2		10.1	319	31.4
	85.8	14.2	–	–	4.02	0.91	4.27	–	–					2.1	13.5	334	6.9	328	31.9
	90.2	9.8	–	–	4.02	0.57	6.83	–	–					2.1	13.0		13.0	315	32.7
	93.6	6.4	–	–	4.02	0.34	11.39	–	–					2.0	14.9	334	10.4	315	30.5
	97.4	2.6	–	–	4.02	0.11	34.17	–	–					2.0	18.2		18.3	311	23.5
	99.4	0.6	–	–	4.02	0.00	∞	–	–					1.9	25.5		12.2	258	28.9
Comp. ex. 2	70.6	29.4	–	–	2.01	0.94	2.13	–	–					2.33	10.0		4.9	864	23.1
	72.9	27.1	–	–	2.01	0.94	2.13	–	–					2.32	9.8		12.2	842	24.7
	66.8	33.2	–	–	2.01	0.94	2.13	–	–					2.33	16.2		5.0	782	19.7
	65.9	33.1	–	–	2.01	0.94	2.13	–	–					2.30	12.3		23.1	694	19.7
	65.6	34.4	–	–	2.01	0.94	2.13	–	–					2.29	14.4		4.7	595	19.1
	70.0	30.1	–	–	2.01	0.94	2.13	–	–					2.30	15.1		7.5	629	22.5
	64.7	35.3	–	–	3.82	0.94	4.05	–	–					2.30	18.0	210	1.4	149	18.2
	68.6	31.4	–	–	4.62	0.94	4.90	–	–					2.32	14.3		1.0	148	20.6
	69.2	30.8	–	–	5.22	0.94	5.54	–	–					2.34	15.3		1.5	166	21.7

[Table 1 (Continued)]

	Composition [mass%]				Fe ion [g/l]	Co ion [g/l]	Fe/Co	Malonic acid [g/l]	Saccharin [g/l]	Current density [mA/cm²]	Duty ratio	pH	Temp	4πNs [T]	Hch [Oe]	Cryst. particle dia. [Å]	Surface roughness [nm]	Film stress [MPa]	Sp. resistance [μΩcm]
	Fe	Co	Ni	Rh															
	65.9	34.1	–	–	5.22	0.94	5.54	–	–					2.29	23.6	180	1.7	102	19.0
	68.6	31.5	–	–	6.03	0.94	6.39	–	–					2.32	19.5		1.6	69	20.9
	69.0	31.0	–	–	6.03	0.94	6.39	–	–					2.31	20.1		1.8	78	21.4
	67.8	32.3	–	–	6.23	0.94	6.60	–	–					2.32	26.4	173	2.1	60	20.4
	69.7	30.3	–	–	7.20	0.94	7.63	–	–					2.26		244	1.8	53	21.9
	73.8	26.2	–	–	3.42	0.52	6.52	–	–					2.30	19.2		2.6	182	26.6
	79.7	20.3	–	–	5.42	0.52	10.35	–	–					2.26	17.8		2.1	224	32.7
	79.9	20.1	–	–	5.42	0.52	10.35	–	–					2.23	17.8		2.8	253	33.2
	82.0	18.0	–	–	5.42	0.52	10.35	–	–					2.16	17.2	220	5.5	294	33.8
	75.1	25.0	–	–	6.43	0.52	12.27	–	–					2.23		225	1.9	220	29.4
	78.3	21.7	–	–	7.43	0.52	14.18	–	–					2.23	20.8	230	2.6	194	32.4
	79.3	20.7	–	–	2.01	0.21	9.58	–	–					2.25	14.4		1.6	132	32.7
	80.6	19.4	–	–	2.51	0.21	12.46	–	–					2.19	14.2		1.7	163	33.5
	84.0	16.0	–	–	4.02	0.23	17.42	–	–					2.14	14.4		1.7	154	34.7
	83.5	16.6	–	–	4.02	0.24	16.96	–	–					2.15	16.2		1.2	96	34.1
	79.9	20.2	–	–	2.01	0.63	3.19	–	–					2.22	17.8		3.5	338	32.7
	66.4	33.6	–	–	2.01	0.63	3.19	–	–					2.35	21.4		0.9	390	20.2
	64.1	35.9	–	–	2.01	0.63	3.19	–	–					2.28	24.7		2.4	248	18.4
	68.2	31.8	–	–	2.01	0.63	3.19	–	–					2.32	20.7		1.6	287	20.5
	70.3	29.7	–	–	2.01	0.63	3.19	–	–					2.35	17.4		1.9	415	22.8
	64.7	35.3	–	–	2.01	0.63	3.19	–	–					2.30	25.0		2.0	217	18.3
	62.7	37.3	–	–	2.01	0.63	3.19	–	–					2.28	28.7		2.0	217	18.3
	67.0	33.0	–	–	2.01	0.94	2.13	–	–					2.35	13.4		6.2	681	19.7
	66.3	33.7	–	–	2.01	1.15	1.74	–	–					2.33	12.2		7.7	767	19.1
	63.1	37.0	–	–	2.01	1.36	1.47	–	–					2.31	12.7		1.8	951	17.7
	65.9	34.2	–	–	2.01	1.36	1.47	–	–					2.30	13.6		2.6	1005	17.5
	62.7	37.3	–	–	2.01	1.36	1.47	–	–					2.27	12.5		2.9	1124	17.5
	64.7	35.3	–	–	2.01	1.36	1.47	–	–					2.31	12.0		2.1	1028	18.2
	65.9	34.8	–	–	2.01	1.36	1.47	–	–					2.31	13.2		2.1	1037	18.2
	63.3	36.8	–	–	2.01	1.36	1.47	–	–					2.29	13.2		2.6	1037	17.5
Comp. ex. 2	65.4	34.8	–	–	2.01	1.36	1.47	–	–					2.31	13.0		1.5	898	18.5

[Table 1 (Continued)]

	Composition [mass%]				Fe ion [g/l]	Co ion [g/l]	Fe/Co	Malonic acid [g/l]	Saccharin [g/l]	Current density [mA/cm²]	Duty ratio	pH	Temp	4πNs [T]	Hch [Oe]	Cryst. particle dia. [Å]	Surface roughness [nm]	Film stress [MPa]	Sp. resistance [μΩcm]
	Fe	Co	Ni	Rh															
Comp. ex. 2	64.2	35.8	-	-	2.01	1.36	1.47	-	-	25.7	0.3	2.2	30	2.32	13.2		2.1	918	18.1
	59.7	40.3	-	-	2.01	1.36	1.47	-	-	12.8	0.3	2.2	30	2.26	21.8		1.2	537	17.1
	66.9	33.1	-	-	2.41	1.36	1.77	-	-	12.8	0.3	2.2	30	2.32	17.8	227	1.5	738	19.4
	71.7	28.3	-	-	3.01	1.36	2.21	-	-	8.3	0.3	2.5	30	2.32	17.2		2.8	619	24.1
	69.8	30.2	-	-	2.01	1.36	1.47	-	-	25.7	0.3	2.5	30	2.33	10.1		3.9	902	22.0
	54.4	45.6	-	-	2.01	1.26	1.60	-	-	19.3	0.3	2.5	30	2.15	56.7		1.1	239	16.3
	70.5	29.5	-	-	2.01	1.26	1.60	-	-	19.3	0.3	2.2	30	2.34	15.5		3.0	902	22.3
	70.1	29.9	-	-	2.01	1.26	1.60	-	-	19.3	0.3	2.2	30	2.34	14.3		2.8	945	22.5
	70.0	30.0	-	-	2.01	1.26	1.60	-	-	19.3	0.3	2.2	30	2.34	13.4		2.9	909	22.1
	59.8	40.2	-	-	1.21	1.26	0.96	-	-	19.3	0.3	2.2	30	2.27	17.8		6.7	810	17.1
	59.8	40.2	-	-	1.21	1.26	0.96	-	-	15.4	0.3	2.2	30	2.27	17.3		2.5	878	17.1
	56.3	43.7	-	-	1.21	1.26	0.96	-	-	15.4	0.3	2.2	30	2.20	16.6		1.0	1110	16.5
	63.0	37.0	-	-	1.61	1.26	1.28	-	-	15.4	0.3	2.2	30	2.27	15.4		1.5	1175	17.5
	64.2	35.8	-	-	1.61	1.26	1.28	-	-	12.8	0.3	2.2	30	2.30	17.7		1.4	1120	18.0
Ex.	70.1	29.9	-	-	1.00	0.52	1.92	0.03	-	25.7	0.3	2.2	30	2.37	12.0		1.1	926	24.4
	60.8	39.3	-	-	1.00	0.52	1.92	0.03	-	12.8	0.3	2.2	30	2.37			1.5		20.0
	67.2	32.8	-	-	1.00	0.52	1.92	0.03	-	12.8	0.3	2.5	30	2.35		180	1.0	706	20.0
	51.0	49.0	-	-	1.00	0.52	1.92	0.03	-	8.3	0.3	2.5	30	2.25	16.5		1.5	650	23.0
	66.4	33.6	-	-	1.00	0.52	1.92	0.03	-	25.7	0.3	2.5	30				3.7	811	23.0
	66.6	33.4	-	-	1.00	0.52	1.92	0.03	-	19.3	0.3	2.2	30	2.37	10.7		1.4	748	
	62.0	38.0	-	-	1.00	0.52	1.92	0.03	-	19.3	0.3	2.2	30				2.2	395	
	61.3	38.7	-	-	1.00	0.52	1.92	0.05	-	15.4	0.3	2.2	30	2.36	10.4		1.5	508	22.3
	65.8	34.2	-	-	1.00	0.52	1.92	0.05	-	15.4	0.3	2.2	30	2.36	9.2		1.2	923	26.1
	65.4	34.6	-	-	1.00	0.52	1.92	0.05	-	19.3	DC	2.2	30		10.5		0.8	1245	28.4
	67.0	33.0	-	-	1.00	0.52	1.92	0.05	-	14.1	DC	2.2	30		11.2		0.9	1294	30.6
	69.7	30.3	-	-	1.00	0.52	1.92	0.03	-	25.7	0.3	2.1	30	2.35	8.7		0.6	820	23.1
	69.0	31.0	-	-	1.00	0.52	1.92	0.05	-	25.7	0.3	2.1	30	2.37	9.0		0.5	950	24.8
Comp. ex. 3	61.2	32.4	-	6.4										2.20	13.8	150	1.5		30

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[0081]

In Example of the present invention, $CoSO_4 \cdot 7H_2O$ (Co ions were 0.52 g/l), $FeSO_4 \cdot 7H_2O$ (Fe ions were 1.00 g/l), NaCl (25 g/l), H_3BO_3 (25 g/l) and malonic acid were added to a plating

5 bath. Sodium saccharin was not added to the above-mentioned plating bath.

[0082]

With respect to the film forming condition, the plating bath temperature was set at 30°C, and the pH of the electrode

10 was set within the range of 2.1 to 2.5. When pulsed current was used for the electroplating method, the duty ratio (ON/OFF) of the pulsed current was set at 0.3. Some CoFe alloys were formed by plating using direct current instead of using pulsed current.

15 [0083]

A plurality of CoFe alloys were formed by plating using the above-mentioned plating bath containing 0.03 (g/l) or 0.05 g/l of malonic acid.

[0084]

20 In Comparative example 1, alloys containing Co and Fe were formed by plating using plating baths containing $CoSO_4 \cdot 7H_2O$ (refer to Table 1 for information on the amount of Co ions), $FeSO_4 \cdot 7H_2O$ (refer to Table 1 for information on the amount of Fe ions), NaCl (25 g/l), H_3BO_3 (25 g/l) and sodium

25 saccharin. In Comparative example 2, alloys containing Co and Fe were formed by plating using plating baths containing $CoSO_4 \cdot 7H_2O$ (refer to Table 1 for information on the amount of Co ions), $FeSO_4 \cdot 7H_2O$ (refer to Table 1 for information on the

amount of Fe ions), NaCl (25 g/l) and H_3BO_3 (25 g/l). In Comparative example 3, a CoFeRh alloy was formed by plating as well. Each of soft magnetic films of Comparative examples was formed by plating with pulsed current under the same film forming condition as that in Example.

[0085]

Each of soft magnetic films formed using the plating baths in the above-mentioned Example and Comparative examples 1 to 3 was used so that relationships between the amount of Fe of the soft magnetic film and various magnetic characteristics were examined. The relationship between the amount of Fe and the saturation magnetic flux density Bs is shown in Fig. 4.

[0086]

As is clear from Fig. 4, with respect to the CoFe alloy formed by plating using the plating bath in Example, when the amount of Fe was adjusted to be about 60% by mass or more, but 70% by mass or less, the saturation magnetic flux density Bs was 2.35 T or more, and it was made clear that the saturation magnetic flux density Bs higher than that of the alloys containing Co and Fe, which were formed by plating using the plating baths in Comparative examples, was able to be achieved.

[0087]

The relationship between the amount of Fe and the coercive force Hc is shown in Fig. 5. Here, 1 (Oe) corresponds to 79 (A/m). As is clear from Fig. 5, with respect to the CoFe alloy formed by plating using the plating

bath in Example, when the amount of Fe was in the range of about 60% by mass to 70% by mass, the coercive force Hc was 1,185 (A/m) or less (= 15 Oe or less), and therefore, the coercive force lower than or equivalent to that of the alloys containing Co and Fe, which were formed by plating using the plating baths in Comparative examples, was able to be achieved.

[0088]

The relationship between the amount of Fe and the specific resistance is shown in Fig. 6. As is clear from Fig. 6, with respect to the CoFe alloy formed by plating using the plating bath in Example, the specific resistance was 20 ($\mu\Omega \cdot cm$) or more, and therefore, the specific resistance higher than or equivalent to that of the alloys containing Co and Fe, which were formed by plating using the plating baths in Comparative examples, was able to be achieved.

[0089]

The relationship between the amount of Fe and the film stress is shown in Fig. 7. As is clear from Fig. 7, with respect to the CoFe alloy formed by plating using the plating bath in Example, a maximum film stress increased to the order of 1,200 (MPa), and therefore, the film stress tended to become larger than that of the alloys containing Co and Fe, which were formed by plating using the plating baths in Comparative examples.

[0090]

With respect to the soft magnetic films formed using the plating baths in the above-mentioned Example and Comparative

examples 1 and 2, the relationship between the amount of Fe
and the crystal particle diameter and the relationship
between the amount of Fe and the center line average
roughness Ra of the film surface were examined.

5   [0091]

Fig. 8 is a graph showing the relationship between the
amount of Fe and the crystal particle diameter. As is clear
from Fig. 8, the crystal particle diameters of the CoFe
alloys formed by plating using the plating baths in Example

10   tended to become smaller than the crystal particle diameters
of the alloys containing Co and Fe formed by plating using
the plating baths in Comparative examples 1 and 2, and
therefore, the crystal particle diameters of the CoFe alloys
formed by plating using the plating baths in Example were

15   able to be controlled at 200 angstroms or less.

[0092]

Fig. 9 is a graph showing the relationship between the
amount of Fe and the center line average roughness Ra of the
film surface. As is clear from Fig. 9, the center line

20   average roughness Ra of the CoFe alloys formed by plating
using the plating baths in Example tended to become smaller
than the center line average roughness Ra of the alloys
containing Co and Fe formed by plating using the plating
baths in Comparative examples 1 and 2, and therefore, the

25   center line average roughness Ra of the film surface of the
CoFe alloys formed by plating using the plating baths in
Example were able to be controlled at 2.5 angstroms or less.

[0093]

Fig. 10 is a graph showing the relationship between the center line average roughness Ra of the film surfaces and the crystal particle diameters of the soft magnetic films formed by plating using the plating baths in Example and Comparative examples 1 and 2. As is clear from Fig. 10, the crystal particle diameters are decreased with decreases in the center line average roughness Ra of the film surfaces. It was made clear that all soft magnetic films formed by plating using the plating baths in Example and Comparative examples 1 and 2 showed in common this tendency, but the center line average roughness Ra of the film surfaces and the crystal particle diameters of the CoFe alloys formed by plating using the plating baths in Example were able to be made very small compared with those of the alloys containing Co and Fe, which were formed by plating using the plating baths in Comparative examples 1 and 2.

[0094]

Fig. 11 is a graph showing the relationship between the center line average roughness Ra of the film surfaces and the saturation magnetic flux densities Bs of the soft magnetic films formed by plating using the plating baths in Example and Comparative examples 1 to 3.

[0095]

As is clear from Fig. 11, the saturation magnetic flux densities Bs are increased with decreases in the center line average roughness Ra of the film surfaces. It was made clear that all soft magnetic films formed by plating using the plating baths in Example and Comparative examples 1 to 3

showed in common this tendency, but the saturation magnetic
flux densities Bs of the CoFe alloys formed by plating using
the plating baths in Example were able to be effectively
increased compared with that of the alloys containing Co and
5   Fe formed by plating using the plating baths in Comparative
examples 1 to 3, and in particular, the saturation magnetic
flux density Bs of 2.35 T or more was able to be achieved
with respect to the CoFe alloy in Example.

[0096]

10   As described above, the CoFe alloys in Example, that is,
formed by plating using the plating baths containing malonic
acid without addition of sodium saccharin can accelerate
microcrystallization and reduce the center line average
roughness Ra of the film surface. In addition, other
15   magnetic characteristics can also be adjusted to be within
the range suitable for a magnetic pole layer and a core layer
of a thin film magnetic head, for example, the saturation
magnetic flux density Bs can be improved and the coercive
force can be reduced.

20   [0097]

When malonic acid is added to the plating bath, since
the above-mentioned malonic acid is a complexing agent, the
trivalent Fe ion contained in the above-mentioned plating
bath is likely to form a complex compound with the above-
25   mentioned malonic acid. As a result, it is believed that Fe
in the CoFe alloy formed by plating primarily is the divalent
Fe ion in the plating bath, and it is believed that trivalent
Fe ions, which cause reduction of the saturation magnetic

flux density Bs, become unlikely to be taken into the CoFe

alloy. Consequently, with respect to the CoFe alloy in

Example, the saturation magnetic flux density Bs is higher

than that of the CoFe alloys in Comparative examples, and the

5   above-mentioned saturation magnetic flux density Bs can be

reliably increased to 2.35 T or more by adjusting the amount

of Fe to be 60% by mass or more, but 70% by mass or less.

[0098]

Experiments on corrosion resistance were performed with

10   respect to each of soft magnetic films in Example and

Comparative examples 1 to 3. In the experiments, a solid

film of each soft magnetic film was formed by plating on a

substrate, and this was processed into a circular pattern of

7 mm in diameter, followed by immersion in an aqueous

15   sulfuric acid of pH 4.0 for 30 minutes. Subsequently,

occurrence of corrosion was observed with a metallurgical

microscope. The experimental results are shown in the

following Table 2.

[0099]

[Table 2]

Plated film name	Composition [mass%]	Surface roughness [nm]	Experimental result of corrosion resistance test	⊙,○,△,×
Comparative example 3	Fe/Co/Rh = 65/33/2	1.4	Corrosion in edge	△
	Fe/Co/Rh = 64/32/4	1.5	Corrosion in edge	△
Comparative example 1	Fe/Co = 68/32	8.1	Corrosion all over surface	×
	Fe/Co = 72/28	4.2	Corrosion all over surface	×
Comparative example 2	Fe/Co = 64/36	1.4	No corrosion	○
	Fe/Co = 70/30	1.8	No corrosion	○
	Fe/Co = 74/26	1.9	No corrosion	○
	Fe/Co = 84/16	1.7	No corrosion	○
	Fe/Co = 90/10	1.8	No corrosion	○
Example	Fe/Co = 64/36	0.8	No corrosion	⊙
	Fe/Co = 70/30	0.5	No corrosion	⊙

⊙: No corrosion is observed.
○: No corrosion is observed, but change in color is observed.
△: Corrosion is partially observed.
×: Corrosion is observed all over the surface.

[0100]

As is clear from Table 2, with respect to the CoFeRh alloy (Comparative example 3), corrosion was observed in the edge portion of the experimental sample. With respect to the alloy containing Co and Fe, formed by plating using the plating bath containing sodium saccharin (Comparative example 1), corrosion was observed all over the experimental sample.

[0101]

On the other hand, with respect to the alloy containing Co and Fe, formed by plating using the plating bath without addition of sodium saccharin (Comparative example 2), although no corrosion was observed in the experimental sample,

there was a change in color of the film surface compared with the CoFe alloys formed by plating using the plating baths containing malonic acid without addition of sodium saccharin (Example). Consequently, it was verified that the CoFe alloys in Example have the corrosion resistance superior to that of each soft magnetic film in Comparative example.

[0102]

The reason the CoFe alloys in Example have the thus excellent corrosion resistance is believed that in the CoFe alloys in Example, microcrystallization is accelerated compared with that in each of the soft magnetic films in Comparative examples, and therefore, the center line average roughness Ra of the film surface is very small.

[0103]

As described above, with respect to the CoFe alloys formed by plating using the plating baths containing malonic acid without addition of sodium saccharin (Example), it was made clear that both of the saturation magnetic flux density Bs and the corrosion resistance can be effectively improved.

[0104]

The soft magnetic films in Example and Comparative example 2 were cut in the direction parallel to the film thickness direction, and states of crystals appeared on the cut surfaces were observed with a transmission electron microscope (TEM).

[0105]

Fig. 12 is a TEM photograph of an alloy containing Co and Fe, formed by plating through an electroplating method

with pulsed current without addition of sodium saccharin nor malonic acid to a plating bath (Comparative example 2). Fig. 13 is a magnified part of the photograph shown in Fig. 12.

[0106]

5   As shown in Fig. 12 and Fig. 13, the soft magnetic film formed by plating is believed to be substantially crystalline. However, the type of crystalline form cannot be determined. As is clear from Fig. 13, not many grain boundaries are observed, and therefore, each crystal is believed to be in

10   the shape of one large lump.

[0107]

Fig. 14 is a TEM photograph of a CoFe alloy formed by plating through an electroplating method with pulsed current while 0.03 g/l of malonic acid is added to a plating bath.

15   Fig. 15 is a magnified part of the photograph shown in Fig. 14.

[0108]

As shown in Fig. 14, in the CoFe alloy, many black stripe-shaped contrasts from a substrate toward the film

20   thickness direction are observed. The reason for this is believed that crystals grow into columnar shapes from the substrate side toward the film surface direction by plating. As shown in the magnified photograph of Fig. 15, grain boundaries can be observed at a plurality of places, and

25   these grain boundaries long extend in the film thickness direction. Therefore, the crystal region sandwiched between the above-mentioned grain boundaries is in a state of a columnar crystal extending in the film thickness direction.

[0109]

Fig. 16 is a TEM photograph of a CoFe alloy formed by plating through an electroplating method with pulsed current while 0.05 g/l of malonic acid is added to a plating bath.
5 Fig. 17 is a magnified part of the photograph shown in Fig. 16.

[0110]

In the CoFe alloy shown in Fig. 16, many black stripe-shaped contrasts from a substrate toward the film thickness
10 direction are observed in a manner similar to that in Fig. 14. The reason for this is believed that crystals grow into columnar shapes from the substrate side toward the film surface direction by plating. In particular, as shown in the magnified photograph of Fig. 17, grain boundaries can be
15 clearly observed at a plurality of places, and these grain boundaries linearly long extend in the film thickness direction. Therefore, the crystal region sandwiched between the above-mentioned grain boundaries is in a state of a columnar crystal linearly extending in the film thickness
20 direction. Furthermore, as shown in Fig. 17, the contrast between white portions and black portions in the above-mentioned columnar crystal can be clearly observed in the photograph, and therefore, it is believed that each columnar crystal is formed by piling up of microcrystals.

25 [0111]

As is clear from Fig. 14 to Fig. 17, when the amount of malonic acid added to the plating bath is adjusted to be 0.05 g/l rather than 0.03 g/l, the columnar crystals extending in

the film thickness direction can be more clearly observed,

these columnar crystals are likely to be formed side by side

in the film surface direction with grain boundaries extending

in the film thickness direction therebetween, and furthermore,

5   the above-mentioned columnar crystals are likely to be formed

by piling up of a plurality of microcrystals.

[0112]

Fig. 18 is a TEM photograph of a CoFe alloy formed by

plating through an electroplating method with direct current

10   while 0.05 g/l of malonic acid is added to a plating bath.

Fig. 19 is a magnified part of the photograph shown in Fig.

18.

[0113]

In the cross-section of the CoFe alloy shown in Fig. 18,

15   many black stripe-shaped contrasts from a substrate toward

the film thickness direction are observed in a manner similar

to those in Fig. 14 and Fig. 16. The reason for this is

believed that crystals grow into columnar shapes from the

substrate side toward the film surface direction by plating.

20   As shown in the magnified photograph of Fig. 19, grain

boundaries can be observed at a plurality of places, and

these grain boundaries long extend in the film thickness

direction. Therefore, the crystal region sandwiched between

the above-mentioned grain boundaries is in a state of a

25   columnar crystal extending in the film thickness direction.

[0114]

The CoFe alloy shown in Fig. 18 and Fig. 19 was formed

by plating with direct current, and therefore, it was

verified that the columnar crystals was able to be formed with direct current as well, when the CoFe alloy was formed by plating using the plating bath containing malonic acid.

[0115]

As described above, it was made clear that columnar crystals extending in the film thickness direction were formed in the CoFe alloy formed by plating with pulsed current or direct current while malonic acid was added to the plating bath. When 0.05 g/l of malonic acid is added, fine columnar crystals are likely to be formed side by side in the film surface direction with grain boundaries extending in the film thickness direction therebetween, and furthermore, these columnar crystals are likely to be formed by piling up of microcrystals compared with that in the case where 0.03 g/l of malonic acid is added. It was also made clear that when the pulsed current was used during formation of the plating, the above-mentioned columnar crystals were likely to be appropriately formed all over the film of the CoFe alloy, and the above-mentioned columnar crystals were finely formed in the film surface direction with grain boundaries extending in the film thickness direction therebetween compared with that in the case where the direct current was used.

[0116]

Fig. 20 to Fig. 22 are scanning electron microscope (SEM) photographs showing the states of the film surfaces of soft magnetic films formed under the following conditions.

[0117]

With respect to the film forming conditions, the current

density was adjusted to be 25.7 (mA/cm2), the duty ratio

(ON/OFF) of the pulsed current was set at 200/800 msec, and

the pH of the electrode was set at 2.2.

[0118]

5   Fig. 20 is a SEM photograph of the film surface of an

alloy containing Co and Fe formed by plating without addition

of malonic acid nor sodium saccharin to a plating bath

(Comparative example 2). Fig. 21 is a SEM photograph of a

CoFe alloy formed by plating while 0.03 g/l of malonic acid

10   is added to a plating bath (Example). Fig. 22 is a SEM

photograph of a CoFe alloy formed by plating while 0.05 g/l

of malonic acid is added to a plating bath (Example).

[0119]

It is clear that the film surface shown in Fig. 22

15   exhibits the smallest surface roughness, followed by the film

surface shown in Fig. 21, and the film surface shown in Fig.

20 exhibits the largest surface roughness. In this manner,

it was made clear that the surface roughness of the film

surface of the CoFe alloy was able to be improved by addition

20   of malonic acid to the plating bath, and when 0.05 g/l of the

above-mentioned malonic acid was added, the surface roughness

of the film surface of the CoFe alloy was able to be further

appropriately improved compared with that in the case where

0.03 g/l of malonic acid was added.

25   [0120]

Fig. 23 is a SIM photograph of a cross-section of a thin

film magnetic head cut along the front (the same surface as

that shown in Fig. 1) toward the film thickness direction

with an FIB (Focused Ion Beam) apparatus and taken with an

SIM (Scanning Ion Microscope), while 0.05 g/l of malonic acid

was added to a plating bath, and a lower magnetic pole layer

and an upper magnetic pole layer were formed by plating with

5   the pulsed current, using the resulting plating bath.

[0121]

The portions indicated by "CoFe plated film" shown in

Fig. 23 are magnetic pole layers, and a NiP plated film to

become a gap is provided between the above-mentioned magnetic

10 pole layers. A three-layer portion of CoFe plated film / NiP

plated film / CoFe plated film corresponds to the magnetic

pole portion 18 shown in Fig. 1. With respect to the CoFe

plated films, the CoFe plated film provided under the NiP

plated film is the lower magnetic pole layer 19, and the CoFe

15 plated film provided on the top of the NiP plated film is the

upper magnetic pole layer 21.

[0122]

As shown in Fig. 23, the film surface of the CoFe plated

film to become the lower magnetic pole layer 19 is flattened.

20 As a result, since the above-mentioned NiP plated film can be

formed into the shape of a flattened surface, the above-

mentioned NiP plated film can be prevented from being formed

into a bend, that is, from being formed into a so-called

smile face shape. The film surface of the above-mentioned

25 upper magnetic pole layer 21 is also flattened. By forming

the lower magnetic pole layer 19 and the upper magnetic pole

layer 21 from the CoFe alloy formed by plating using the

plating bath containing malonic acid, as described above,

surface roughness of the film surface of the above-mentioned

magnetic pole layers 19 and 21 can be reduced, and be formed

to become flattened, so that the NiP plated film sandwiched

between the above-mentioned magnetic pole layers 19 and 21

5   can be formed into the shape of a rectangle parallel to the

width direction. In the magnetic pole portion 18 formed with

a very small width dimension and height dimension, the gap

layer must be formed into the predetermined shape in the

width direction in order to have excellent recoding

10   characteristics under an increase in packing density. This

can be realized by forming the lower magnetic pole layer 19

and the upper magnetic pole layer 21 from the CoFe alloy

formed by plating using the plating bath containing malonic

acid.

15   [0123]

    Fig. 24 and Fig. 25 are graphs prepared based on the

experimental results shown in the following Table 3. Fig. 24

is a graph showing the relationship between the malonic acid

addition concentration and the saturation magnetic flux

20   density Bs, the coercive force Hc and the anisotropic

magnetic field Hk of a CoFe alloy. Here, 1 (Oe) corresponds

to 79 (A/m).

        [0124]

[Table 3]

Malonic acid [g/l]	Bs [T]	Hch [Oe]	Surface roughness [nm]	Film stress [MPa]	Specific resistance [μΩcm]
0.00	2.25	16.5	3.6	723	24.9
0.01	2.29	16.7	2.7	838	25.1
0.02	2.30	14.8	2.7	847	23.2
0.03	2.37	12.0	1.1	926	24.4
0.05	2.37	9.0	0.5	950	24.8

[0125]

As shown in Fig. 3, with respect to each sample, a CoFe alloy was formed by plating through an electroplating method with pulsed current while the amount of addition of malonic acid to a plating bath was varied. With respect to the sample in which the amount of addition of malonic acid was 0.00 g/l, a CoFe alloy in which the amount of Fe of 71.1% by mass and the amount of Co of 28.9% by mass was produced, with respect to the sample in which the amount of addition of malonic acid was 0.01 g/l, a CoFe alloy in which the amount of Fe of 70% by mass and the amount of Co of 30% by mass was produced, with respect to the sample in which the amount of addition of malonic acid was 0.02 g/l, a CoFe alloy in which the amount of Fe of 70.3% by mass and the amount of Co of 29.7% by mass was produced, with respect to the sample in which the amount of addition of malonic acid was 0.03 g/l, a CoFe alloy in which the amount of Fe of 70.1% by mass and the amount of Co of 29.9% by mass was produced, and with respect to the sample in which the amount of addition of malonic acid was 0.05 g/l, a CoFe alloy in which the amount of Fe of 69% by mass and the amount of Co of 31% by mass was produced. As

described above, the compositional ratios of the CoFe alloys were not significantly different from each other.

[0126]

As is clear from Fig. 24, the saturation magnetic flux density Bs was increased with an increase in the amount of addition of malonic acid to the plating bath, and in particular, when the above-mentioned amount of addition of malonic acid became 0.03 g/l or more, the saturation magnetic flux density Bs of the above-mentioned CoFe alloy was able to be increased to 2.35 T or more.

[0127]

It was made clear that the coercive force Hc was decreased with an increase in the amount of addition of malonic acid to the plating bath.

[0128]

Fig. 25 is a graph showing the relationship between the malonic acid addition concentration and the center line average roughness Ra of the film surface of a CoFe alloy, the specific resistance and the film stress.

[0129]

It was made clear from Fig. 25 that the center line average roughness Ra of the film surface of the CoFe alloy was reduced with an increase in the amount of addition of malonic acid to the plating bath, and in particular, when the above-mentioned amount of addition of malonic acid became 0.03 g/l or more, the above-mentioned center line average roughness Ra of the CoFe alloy was reduced to 2.5 angstroms or less.

[0130]

It was made clear from this experimental result that the amount of addition of malonic acid to the plating bath was preferably 0.03 g/l or more, and the lower limit was preferably 0.05 g/l or less because the saturation magnetic flux density was increased to 2.35 T or more.

[0131]

[Advantages]

The soft magnetic film of the present invention described above in detail is a plated film composed of Co and Fe, and columnar crystals extending in the film thickness direction are provided.

[0132]

In the present invention, columnar crystals extending in the film thickness direction are formed, and thereby, improvement in the surface roughness of the film surface and improvement in the corrosion resistance can be achieved. Furthermore, the saturation magnetic flux density Bs can also be improved by making the crystal fine and eliminating the need for adding the noble metal element.

[0133]

That is, according to the CoFe alloy of the present invention, both of the corrosion resistance and the saturation magnetic flux density Bs can be improved, and specifically, the above-mentioned saturation magnetic flux density Bs can be increased to 2.35 T or more.

[0134]

In the method for manufacturing a CoFe alloy of the

present invention, malonic acid is added to the plating bath, and thereby, degradation of the plating bath can be reduced than ever. Since crystals in the soft magnetic film formed by plating can be made fine, and deposition of Fe^{3+} in the above-mentioned soft magnetic film can be reduced by addition of the above-mentioned malonic acid, the manufacturing method of the present invention can improve both of the corrosion resistance and the saturation magnetic flux density Bs of the above-mentioned soft magnetic film.

[Brief Description of the Drawings]

[Fig. 1]

Fig. 1 is a partial front view of a thin film magnetic head according to the first embodiment of the present invention.

[Fig. 2]

Fig. 2 is a vertical sectional view of the portion shown in Fig. 1.

[Fig. 3]

Fig. 3 is a partial front view of a thin film magnetic head according to the second embodiment of the present invention.

[Fig. 4]

Fig. 4 is a graph showing the relationship between the amount of Fe and the saturation magnetic flux density Bs of each soft magnetic film in Example and Comparative examples 1 to 3 formed by plating under the condition shown in Table 1.

[Fig. 5]

Fig. 5 is a graph showing the relationship between the

amount of Fe and the coercive force Hc of each soft magnetic film in Example and Comparative examples 1 to 3 formed by plating under the condition shown in Table 1.

[Fig. 6]

5   Fig. 6 is a graph showing the relationship between the amount of Fe and the specific resistance of each soft magnetic film in Example and Comparative examples 1 and 2 formed by plating under the condition shown in Table 1.

[Fig. 7]

10   Fig. 7 is a graph showing the relationship between the amount of Fe and the film stress of each soft magnetic film in Example and Comparative examples 1 and 2 formed by plating under the condition shown in Table 1.

[Fig. 8]

15   Fig. 8 is a graph showing the relationship between the amount of Fe and the crystal particle diameter of each soft magnetic film in Example and Comparative examples 1 and 2 formed by plating under the condition shown in Table 1.

[Fig. 9]

20   Fig. 9 is a graph showing the relationship between the amount of Fe and the center line average roughness Ra of the film surface of each soft magnetic film in Example and Comparative examples 1 and 9 formed by plating under the condition shown in Table 1.

25   [Fig. 10]

        Fig. 10 is a graph showing the relationship between the center line average roughness and the crystal particle diameter of each soft magnetic film in Example and

Comparative examples 1 and 2 formed by plating under the condition shown in Table 1.

[Fig. 11]

Fig. 11 is a graph showing the relationship between the center line average roughness Ra of the film surface and the saturation magnetic flux density Bs of each soft magnetic film in Example and Comparative examples 1 to 3 formed by plating under the condition shown in Table 1.

[Fig. 12]

Fig. 12 is a TEM photograph of a cross-section parallel to the film thickness direction of a CoFe alloy formed by plating with pulsed current without addition of malonic acid nor sodium saccharin to a plating bath.

[Fig. 13]

Fig. 13 is a magnified part of the TEM photograph shown in Fig. 12.

[Fig. 14]

Fig. 14 is a TEM photograph of a cross-section parallel to the film thickness direction of a CoFe alloy formed by plating with pulsed current while 0.03 g/l of malonic acid is added to a plating bath.

[Fig. 15]

Fig. 15 is a magnified part of the TEM photograph shown in Fig. 14.

[Fig. 16]

Fig. 16 is a TEM photograph of a cross-section parallel to the film thickness direction of a CoFe alloy formed by plating with pulsed current while 0.05 g/l of malonic acid is

added to a plating bath.

[Fig. 17]

Fig. 17 is a magnified part of the TEM photograph shown in Fig. 16.

[Fig. 18]

Fig. 18 is a TEM photograph of a cross-section parallel to the film thickness direction of a CoFe alloy formed by plating with direct current while 0.05 g/l of malonic acid is added to a plating bath.

[Fig. 19]

Fig. 19 is a magnified part of the TEM photograph shown in Fig. 18.

[Fig. 20]

Fig. 20 is a SEM photograph of the film surface of a CoFe alloy formed by plating with pulsed current without addition of malonic acid nor sodium saccharin to a plating bath.

[Fig. 21]

Fig. 21 is a SEM photograph of the film surface of a CoFe alloy formed by plating with pulsed current while 0.03 g/l of malonic acid is added to a plating bath.

[Fig. 22]

Fig. 22 is a SEM photograph of the film surface of a CoFe alloy formed by plating with pulsed current while 0.05 g/l of malonic acid is added to a plating bath.

[Fig. 23]

Fig. 23 is a SIM photograph of a cross-section parallel to the film thickness direction of a magnetic pole portion of

a thin film magnetic head, while a lower magnetic pole layer
and an upper magnetic pole layer of the above-mentioned
magnetic pole portion are formed from the CoFe alloy of the
present invention.

5   [Fig. 24]

Fig. 24 is a graph showing the relationship between the
amount of addition of malonic acid to a plating bath and the
saturation magnetic flux density Bs, the coercive force Hc
and the anisotropic magnetic field Hk of a CoFe alloy formed

10   by plating.

[Fig. 25]

Fig. 25 is a graph showing the relationship between the
amount of addition of malonic acid to a plating bath and the
specific resistance, the surface roughness and the film

15   stress of a CoFe alloy formed by plating.

[Reference Numerals]

11:   slider

10:   magnetoresistive element

16:   lower core layer (upper shield layer)

20   18:   magnetic pole portion

19:   lower magnetic pole layer

20:   gap layer

21:   upper magnetic pole layer

22 and 46:   upper core layer

25   41:   magnetic gap layer

[Name of Document]   ABSTRACT

[Abstract]

[Object] To provide a soft magnetic film which is composed of Co and Fe, which contains no impurity, e.g. S (sulfur),

5 and which can improve both the saturation magnetic flux density and the corrosion resistance by microcrystallization, a thin film magnetic head using this soft magnetic film, a method for manufacturing the above-mentioned soft magnetic film and a method for manufacturing the above-mentioned thin

10 film magnetic head.

[Solving Means] A soft magnetic film of the present invention is a plated film composed of Co and Fe, and columnar crystals extending in the film thickness direction are provided. In the present invention, columnar crystals

15 extending in the film thickness direction are provided so that an improvement in the surface roughness of the film surface and an improvement in the corrosion resistance can be achieved. Furthermore, the saturation magnetic flux density Bs can also be improved by making the crystal fine and

20 eliminating the need for addition of the noble metal element. That is, according to a CoFe alloy of the present invention, both the corrosion resistance and the saturation magnetic flux density Bs can be improved, and specifically, the above-mentioned saturation magnetic flux density Bs can be

25 increased to 2.35 T or more.